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Mechanical Testing on Resistance Spot Weld Nuggets of AISI 316L Stainless Steel Sheets

[1]K.Gopalakrishnan, [2]S.Gokulakrishnan
UG Students
Department of Mechanical Engineering
R.M.K Engineering College
Chennai, INDIA

Abstract— **Resistance welding is a thermo-electric process in which heat is generated due to the resistance at the interface of the sheets to be joined by passing an electrical current through the sheets for a precisely controlled time and under a controlled pressure. Resistance spot welding (RSW) is a popular method in joining thin sheets used in various manufacturing, automobile, aerospace and packing industries. RSW is a complicated process which involves the interactions of electrical, thermal, mechanical and metallurgical phenomena. In spot welding process, the sheets are placed one over the other (overlapped) and positioned between the water cooled copper electrodes. The electrical current is passed between the electrodes for a short period of time in order to generate the heat.**

As the demand for spot welding is drastically increased due to the increase in the production of automotive and biomedical components, a detailed study on the quality of weld generated during the Resistance spot welding is required. It is understood from the literature, a tremendous amount of work has been conducted on the resistance spot welding of various materials used in automobile and other industrial sectors. In this research work, an attempt is made to experimentally investigate the quality of the weld obtained by resistance spot welding of Austenitic Stainless Steel type 316L of equal thickness (1.6 mm + 1.6 mm). Experimental trials are conducted by varying the process parameters such as, electrode tip diameter, welding current and heating time to measure the nugget size and shape and to predict the strength of the resistance spot weld.

Index Terms— **Resistance Spot Welding, weld strength, weld nugget, 316L Steel**

I. INTRODUCTION

Spot welding involves the joining of two or more pieces of sheet metal in localized areas where melting and coalescence of a small volume of material occurs from heating caused by resistance to the passage of an electric current. This process is typically used to obtain a lap joint of sheet metal parts. A common example is the mass production of automobiles [1], where a typical automobile may contain more than 5000 spot welds. Resistance welding is an oldest technique of the electric welding processes and still a successful technique in use by industrial sectors. In this process, the weld is made by a combination of heat, pressure and time. As the name resistance welding implies, it is the resistance offered by the material to be welded to current flow that causes a localized heating in the part. The pressure exerted by the tongs and electrode tips, through which the current flows, holds the sheets to be welded in intimate contact before, during and after the welding current time cycle. The required amount of time current flows in the joint is determined by material thickness and type, the amount of current flowing, and the cross-sectional area of the welding tip contact surfaces. The schematic diagram of the resistance spot welding process is illustrated in Figure 1.1.

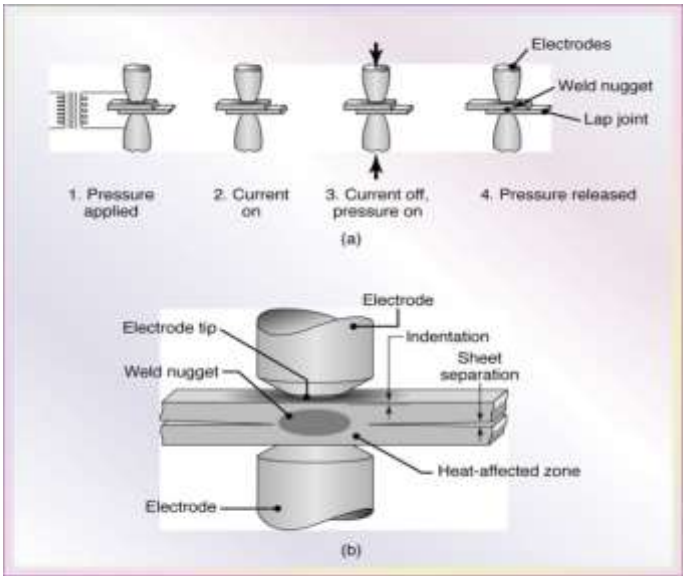

Figure.1 Schematic diagram of Resistance Welding Process

II. RSW PROCESS

In resistance spot welding process, a number of discrete time events are happening as depicted in the Figure 2.

1. Squeeze time.
2. Heating Time or Welding time.
3. Holding time.
4. Cooling time or off time.

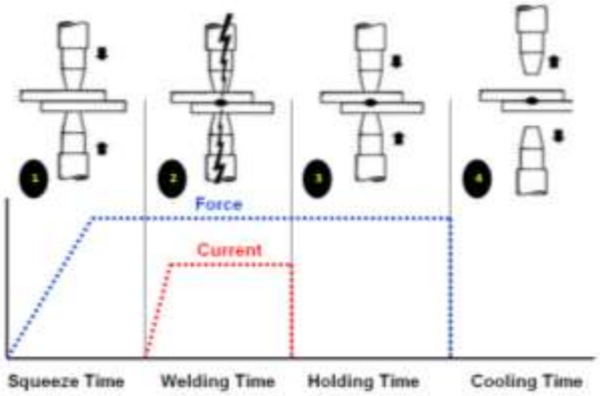

Figure.2 The RSW process sequence

During the squeeze time, the copper electrodes are moving together and force is applied on the work pieces (presses together) in order to build up necessary resistance during the heat generation. In welding cycle, the applied electrode force which in turn balances the electrode magnetic forces that misplace the welding joint. The heating or weld time is the time during which a set amount of current flows through the work pieces. In hold time after the application of current, applied pressure is maintained, in order to form the welding nugget. Cooling time is the time event when the pressure is released before doing the next weld on the work piece. Hence, the nugget formation can be characterized as function of welding variables such as electrode force, current and welding time. The electrical and thermal contact resistances are a function of the applied pressure. The applied force is an important factor which affects the resistance spot process especially in the initial stages of the heating cycle. With the application of high electrode force the contact resistance at metal to metal interface reduces which results in the reduction of joule heating effect. Therefore, the welding current is the most contributing factor during the formation of welding nugget. The heating or welding time plays a crucial role, especially if the heating time is prolonged, expulsion occurs, which means that the molten metal is expelled from welding nugget as shower of sparks. However, if the heating time is short results in cold weld in such cases no welding nugget is formed

III. EXPERIMENTAL STUDIES

In the present investigation, a series of austenitic stainless steel of grade 316L sheets are selected and welded using 50 kVA resistance spot welding machine available at National Institute of Technology, Tiruchirappalli. The welding trials are carried out by fixing cooling water flow rate, electrode force, materials type, hold time and squeeze time and changing electrode tip diameter, welding current and heating time. All series are subjected to tensile-peel off and tensile-shear tests in order to ensure the weld integrity and the strength.

IV. MATERIAL

AISI Type 316L austenitic stainless steel sheets of two different thicknesses such as 1.6 mm and 2.0 mm are chosen as the base metal for this study. Samples with equal dimensions of 100 x 30 x 1.6 mm and 100 x 30 x 2.0 mm are provided and cleaned before welding, using acetone. The chemical composition of the selected SS 316L grade steel is presented in Table 1.The electrodes utilized for conducting resistance spot welding trials are a Class II copper alloy, of a composition of 99.2% Cu and 0.8% Cr.

Table 1 Chemical composition (wt.%) of AISI type 316L steel

Name of the element	**C**	**Si**	**Mn**	**S**	**P**	**Cr**	**Ni**
Composition (%)	0.025	0.379	1.323	0.005	0.029	16.542	10.326
Reference (%)	0.030	1	2.00	0.030	0.045	16.0-18.0	10.0-15.0
Name of the element	**Mo**	**Cu**	**Co**	**Ti**	**V**	**W**	**Fe**
Composition (%)	2.102	0.346	0.005	0.009	0.036	0.003	68.9
Reference (%)	2.0-3.0	---	---	0.100	---	---	---

V. EXPERIMENTS

Spot welding is performed using a 50 kVA 3 phase DC pedestal type resistance spot welding machine operating at 50 / 60 Hz, controlled by a Microprocessor controller (refer Figure 1). Welding trials are conducted using a 81^{o} truncated cone nose, class 2 electrode with three different face diameters such as 6, 7 and 8 mm with 3.2 kN electrode force and 10 cycles squeeze time, which are utilized for welding 1.6 mm thick AISI 316L stainless steel sheets. Initially, the welding piece samples, 1.6 mm+1.6 mm steel sheets are prepared as shown in figure 2. After that, these samples are overlapped with 30 mm spacing and welding. The cooling water

temperature is maintained as 24°C for conducting the experimental trials.

Resistance spot welding experiments are using the parameters as indicated in Table 2 on 1.6mm+1.6mm thick lapped AISI 316L stainless steel sheets to investigate the effect of input process parameters on nugget size i.e. nugget length and nugget width.The experimental trials are conducted by varying three different sets of welding parameters such as electrode diameter, welding current and heating time as per the design matrix developed in this work. The values of the welding parameters used and the number of experiments conducted for each set are shown in Table 3. One set of welded samples is used for macro examination and other one is utilized for performing the tensile shear test.

Table 2 Resistance spot welding parameters

Sl.No	Electrode Tip Diameter,mm	Welding Current, kA	Heating time, cycles	Electrode force, kN	Squeeze time, cycles	Hold time, cycles
1	6	7	7			
2	7	8	8	3.2	10	10
3	8	9	9			

The design matrix is to be developed according to the full factorial concept which gives rise to 27 trials of welding experiments to be carried out at the prescribed ambient conditions. After performing the spot welding, the specimens are cut accordingly for various examinations.

Specimen No.	Electrode tip diameter, mm	Welding Current, kA	Heating time, cycles
1	8	7	7
2	8	8	7
3	8	7	8
4	8	8	8
5	8	9	9
6	8	9	7
7	8	9	8
8	8	7	9
9	8	8	9
10	7	8	8
11	7	8	7
12	7	7	7
13	7	9	7
14	7	8	9
15	7	7	9
16	7	7	8
17	7	9	8
18	7	9	9
19	6	9	9
20	6	9	7
21	6	8	9
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23	6	7	7
24	6	9	8
25	6	8	8
26	6	7	9
27	6	8	7

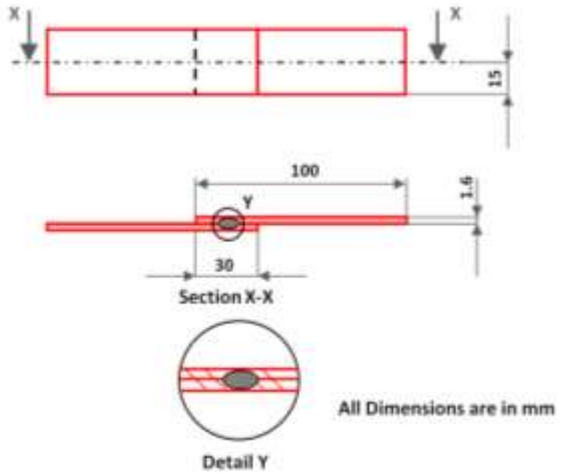


Figure 2 The size of the resistance spot welded specimen – tensile test

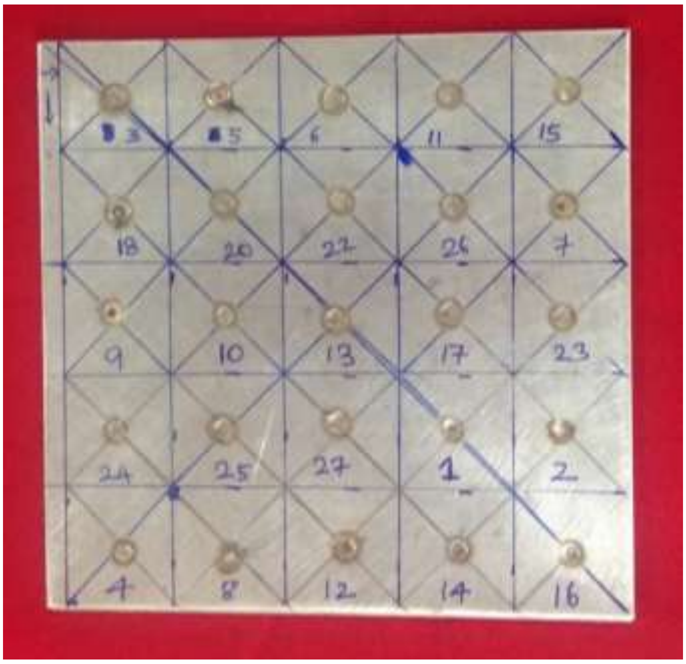
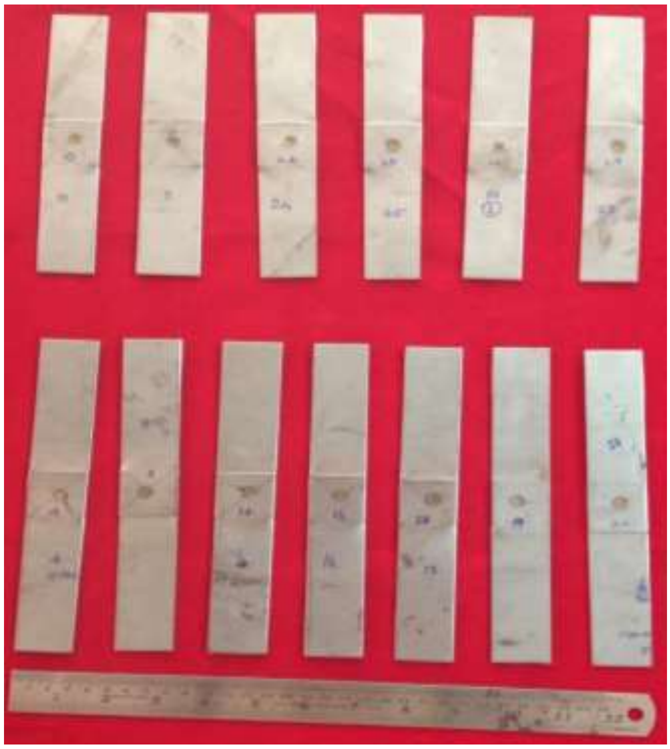


Figure 3 Resistance spot welded specimen – Metallographic examination

Electrode tip diameter is varied from 6 mm to 8 mm, Welding current from 7 kA to 9 kA and the Heating time from 7 cycles to 9 cycles to have a broad data base of input and output variables. By incorporating the factorial model of the design of experiment concept the three levels of the three variables would result in $3^3 = 27$ different combinations of the levels of individual variable. Figure 3 shows the spot welding trials carried out on AISI 316L stainless steel sheet for predicting the Nugget size using optical microscopy. After welding, specimens are cut at transverse sections at the mid-length position of the welds using precision diamond cutter machine to obtain the cross section of the spot weld. The cross sectioned samples were then cut into small pieces of size 50 x 25 x 1.6 mm by using Metal cut abrasive cutting machine. The cross sectioned samples are ground and polished. Grinding is carried out using abrasive sand papers that have grades such as 240, 360, 400, 600, and 800 and 1200, starting with the roughest till finest grade. Then these samples were polished with diamond solution followed by Alumina (Al_2O_3, 0.05µm) colloidal solution. All the samples are cleaned before being etched with Aquaregia a mixture of 25ml HNO_3 + 25ml of Water + 50ml of HCl to display the weld nugget. The weld nugget measurements i.e. nugget diameter (D1) and thickness (D2) are made using an optical microscopy with an Image Analysis system.

VI. TENSILE SHEAR TEST

The welded sheets are subjected to tensile-shear tests in a 50 kN Universal Testing Machine of Tinius Olsen make at laboratory conditions. The tensile speed is maintained as contact during test. Some of the spot welded tensile shear test specimens are shown in Figure4.The dimensions of the weld nugget and the maximum load carried by the resistance spot welded specimen under different input process parameters on 1.6 mm + 1.6 mm thick AISI 316L stainless steel sheet are presented in the Table 4.



Specimen no.	Electrode dia., mm	Welding Current, kA	Heating time, Cycles	Ultimate force, N	D1,mm	D2,mm
1	8	7	7	8990	4.236	2.185
2	8	8	7	9510	4.706	1.933
3	8	7	8	8550	5.265	2.095
4	8	8	8	10100	5.434	1.868
5	8	9	9	11800	5.53	1.909
6	8	9	7	10800	5.182	2.057
7	8	9	8	11200	5.253	1.947
8	8	7	9	8980	5.488	1.832
9	8	8	9	9720	5.535	1.957
10	7	8	8	9840	5.3	2.197
11	7	8	7	9540	5.223	1.983
12	7	7	7	8190	5.235	1.849
13	7	9	7	11700	5.741	1.725
14	7	8	9	10100	4.724	2.08
15	7	7	9	8540	4.883	1.94
16	7	7	8	9180	4.354	1.838
17	7	9	8	11800	6.269	2.045
18	7	9	9	13400	6.228	1.659
19	6	9	9	13000	5.963	1.347
20	6	9	7	10400	4.906	1.839
21	6	8	9	10800	5.106	1.916
22	6	7	8	10900	5.021	2.008
23	6	7	7	9230	4.725	1.807
24	6	9	8	11700	5.952	1.967
25	6	8	8	10700	5.293	1.974
26	6	7	9	10200	4.907	1.849
27	6	8	7	10200	5.105	1.933

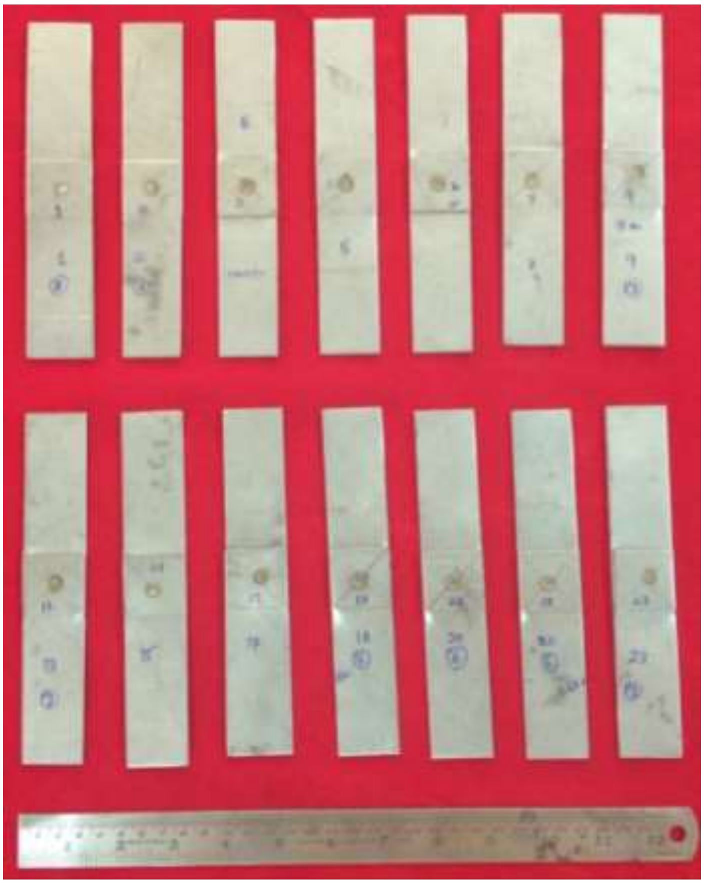
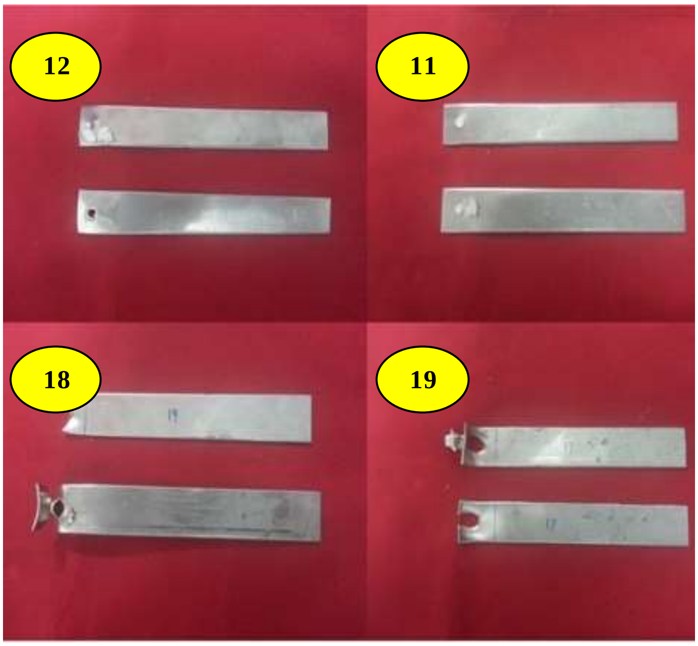


Table 4 Nugget Dimension and Maximum Load

Based on the tensile shear test tests, it is observed that there are three types of breaking failure are occurred in resistance spot welds, they are (1) knotting, (2) separation and, (3) tearing. The Samples failed in these types are shown in Figure 5.



It is evident from the results presented in the Table 4, increasing welding current causes high heat input to weld zone and extending weld nugget, so the maximum load carried by the joints also increases at constant electrode spot diameter and heating time. It is also observed that increasing the electrode spot diameter from 6 mm to 7 mm, there is a considerable increase in the maximum load carried by the joints from 13 kN to 13.4 kN, however, further increase in diameter to 8 mm material expulsion or weld splash is occurred in between two sheets which reduces the load carrying capacity of the joint.

VII. CONCLUSION

As a result of the work carried at 3.2 kN electrode force, the obtained results are given below:

- In the joining of 1.6 mm AISI 316L Stainless steel sheets, maximum load carried by the joint is obtained at 7 mm electrode spot diameter and 9 kA welding current in 9 cycles heating time.
- At constant electrode spot diameter and heating time, when the welding current increases, which in turn cause high heat input to weld zone and extending weld nugget, so the maximum load carried by the joints also increases.
- During the tests, three types of breaking failure are observed as: (1) knotting, (2) separation and (3) tearing.

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